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FOREIGN TECHNOLOGY DIVISION

RADIO-ABSORBING MATERIALS

by

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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
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Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere. When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

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RADIO-ABSORBING MATERIALS. Survey/coverage of foreign works during the period of 1953-1964.

Engineer Ya. A. Shneyderman.

Recently abroad in connection with rapid development of radar technology methods and means of antiradar protection of flight vehicles, which facilitate breach/inrush of aircraft and rockets through lines of air defense intensively are developed/processed. On the intensification of works in this direction it is possible to judge a sharp increase in the expenditures of USAF [United States Air Force] for the development of the combat means with radar - with 35.5 million dollars in 1962 to 119 million dollars in 1963 and 155 million dollars each in 1964 [1].

Utilization of radio-absorbing materials, which ensure decrease of effective surface of scattering of aircraft and rockets, is one of effective combat means with radar. The value of this surface $S_{эф}$ is connected with range D of the detection of aircraft by radars of certain power with formula [2] $D=K\sqrt[4]{S_{эфф}}$, where K - proportionality factor.

Therefore decrease of effective surface of scattering 100 times reduces detection range of objects more than three times. The rockets Titan-2, for example, have forepart/nose ones of cone, which "substantially increase" their ability to penetrate through anti-missile defense [3].

At present in USA are realized (on contract with USAF) two programs, in which is outlined development and utilization of radio-absorbing materials: program LORV (Low Observable Re-entry Vehicle - flight vehicles with reduced radar detectability) and program REX (Reduced EXoatmospheric cross-section - reduced radar cross section in flight in exosphere).

Fields of application of radio-absorbing materials are not contained by this form of utilization. Questions of change of the characteristics after all of materials and characteristics of antenna systems conditioned the need of improving available and the development of the new anechoic chambers, in which the walls, floor and ceiling were made from the radio-absorbing materials. In the anechoic chambers radio frequency interference virtually is absent, which provides the required accuracy of measurements. Theoretically the level of the power reflected in the anechoic chamber composes 0.1% or - 40 dB, but virtually the level of the power reflected is considerably below due to the diffraction on the edges/fins of corrugations. The radio-absorbing materials are used also for shielding of airborne RLS from the interferences of the caused by undesirable reflection signals and for shielding of crew from the harmful radar radiation/emission of aircraft equipment. Materials for the inserts in the waveguides and the coaxial lines compose special group.

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Principle of operation of such materials consists in the fact that absorbed energy transforms itself into different types of electromechanical work in most radio-absorbing material. During the reaction with such materials of radar signals the processes of absorption, scattering and interference of electromagnetic waves [2] occur. The absorption of electromagnetic waves is their weakening during the propagation in the radio-absorbing material, wave energy here partially passes into the heat. The process of scattering is the conversion of the flow propagated in the radio-absorbing material of electromagnetic energy of determinate direction into the flows of all possible directions, which is caused by the structural heterogeneity of material. This heterogeneity is created by the impregnation of one substance into another. The process of the interference of electromagnetic waves is completely similar to optical interference. The interference of electromagnetic waves conditions the value reflectivity of material and the direction of its secondary emission.

Fundamental requirements, imposed on radio-absorbing materials, are such:

1) maximum absorption of electromagnetic waves;

2) minimum reflection;

3) broad band of absorbed wavelengths;

4) high mechanical properties;

5) minimum clearance and weight;

6) capability to work over wide limits of temperatures.

Requirements of maximum absorption and minimum reflection are contradictory, since obtaining minimum reflection is possible only upon gradual transfer from weakly absorbing medium to strongly absorbing medium, at the same time physical properties of strongly attenuating material sharply differ from properties of weakly absorbing medium, in which are propagated well electromagnetic waves. As a result of this sharp difference into the physical properties of two media, the electromagnetic waves are reflected from the interface.

For electromagnetic waves, which arrive from medium 1 it is normal to surface of medium 2, portion of reflected energy is determined from formula [4] $R=(K-1)/(1+K)$, where R - reflection coefficient. Value K is determined from formula $K=Z_2/Z_1$, where $Z_1 Z_2$ - complete resistance of medium 1 and 2. Complete resistance of medium is expressed in the following manner: $Z_1=\sqrt{\mu_1/\epsilon_1}$ and $Z_2=\sqrt{\mu_2/\epsilon_2}$, where μ - magnetic permeability and ϵ - dielectric constant.

In order to obtain reflection coefficient, equal to zero, necessarily observance of equality $Z_2=Z_1$. For the case, when air $\epsilon_1=1$ and $\mu_1=1$ is medium 1. Then it is necessary that $\mu_2=\epsilon_2$ hence it follows that if the radio-absorbing material has $\mu=1$, then it is necessary that it ϵ would be also close to one.

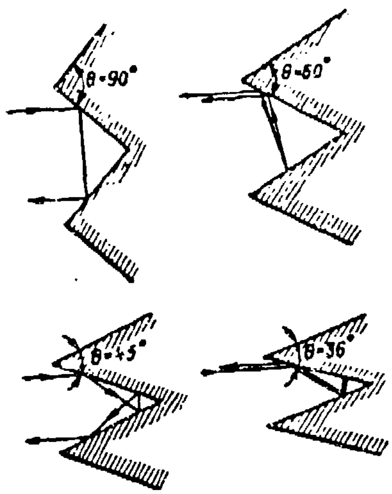

Fig. 1. Dependence of apex angle of the pyramids of the corrugation of the face of the radio-absorbing material on a number of reflections within the cells.

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This material must be very porous. However, in this case ever it is not possible to attain complete equality $\epsilon=1$, therefore for decreasing the residual/remanent reflection the front surface of material is made cellular, pyramidal or spiny, increasing thereby the number of reflections (Fig. 1). In this case it is profitable to have small apex angle of pyramids or pins in order to avoid the possible return of energy after two reflections (90°), three reflections (60°), four reflections (36°), etc.

According to operating principle radio-absorbing materials can be broken [2] into two groups. The first group includes interference type materials, which call the extinction of electromagnetic waves due to their interference. The selection of the thickness of this material is determined by wavelength and by values of the dielectric and magnetic constants of the material: $l=\lambda/4\sqrt{\epsilon\mu}$, where l - thickness of material, λ - wavelength, ϵ and μ - dielectric and magnetic permeabilities. Materials of this type, are intended for absorbing the short waves, can be sufficiently thin[1].

FOOTNOTE [1]. Calculation of the thickness of single-layer radio-absorbing material and width of bands of the absorbed frequencies is given in the collection of labor/works Pros. of the National Electionics Conf. of 1958, Oct 13-15, vol XIV, p 688; calculation of the effectiveness of the thin radio-absorbing coatings on the conducting objects, irradiated by long-wave radar radiation/emission, is given in journal Pros. IRE, 1960, Sept., vol. 48 No 9, p 1636-1642. ENDFOOTNOTE.

For the specific wavelength the value of the thickness of such materials, and also values μ and ϵ must have very low divergences from the given ones. Such materials work well only during the normal incidence of waves. At other angles of incidence the coefficient of reflection of materials sharply increases/grows. (Reflection coefficient it is connected with the angle of incidence of wave with formula [4] $R = (1 - \cos\alpha)/(1 + \cos\alpha)$, R - coefficient of reflection, a - angle of incidence of wave, calculated off normal to the surface of reflection).

Second group includes materials, in which energy of electromagnetic ones oxen is converted into thermal energy due to induction of scattered light currents, magnetic-hysteresis or high-frequency dielectric losses.

With respect to electrical and magnetic properties radio-absorbing materials can be divided into dielectric ones and magnetodielectric ones. By range of work are distinguished two types of the radio-absorbing materials: narrow-band and wide-range.

Simplest narrow-band material is resonance absorber, which consists of homogeneous dielectric layer, superimposed to shielded metal. Thickness l of dielectric layer, its dielectric constant ϵ and dielectric power factor - tgδ are selected by such, that the coefficient of reflection of the incident electromagnetic waves is equal to zero. The absence of reflection from this material is explained by extinction with interference of the electromagnetic waves, reflected from the surface of metal and from the dielectric layer. In this case the waves are displaced relative to each other to the half-waves and have equal amplitudes. The maximum divergence of the resonance frequency of the absorbed radiation/emission must not exceed (without significant decrease in the effectiveness of energy absorption) ±5% [5]. The coefficient of reflection of energy is determined also by the angle of incidence of radiation/emission on the material. Material begins to badly/poorly absorb incident radiation at the angles of its incidence 70-80° C, in this case from the material it is reflected by 2-3% of energy [5].

For wide-range materials minimum (critical) frequency is determined by thickness of material, which is considerably greater than in narrow-band ones. In contrast to the narrow-band wide-range materials absorb the large part of the energy before electromagnetic waves they will achieve the reflecting surface. In wide-range materials is used [6] the principle of the so-called "electric swamp" ("Electric swamp"), according to which the value of electrical losses increases/grows along the thickness of absorber.

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As the example of a wide-range material of the type of "electrical swamp/marsh" can serve material [6], which consists of the alternating dielectric layers with the low losses and the thin sheets of the badly/poorly conducting material, whose surface resistor/resistance decreases by the constant value in proportion to the approximation/approach of sheets to the shielded metal. The characteristics of this material can be calculated according to the theory of transmission lines [7].

Designed thus dependence of reflection coefficient from wavelength of absorbed radiation/emission for seven-layer material is shown in Fig. 2, and for two-layered materials in Fig. 3. The typical dependence of the amount of the radiated power, reflected by wide-range material, from the angle of incidence of radiation/emission, it is shown in Fig. 4. Usually the radio-absorbing materials reflect 1% of electromagnetic energy, in some materials this value can be lowered to 0.01%.

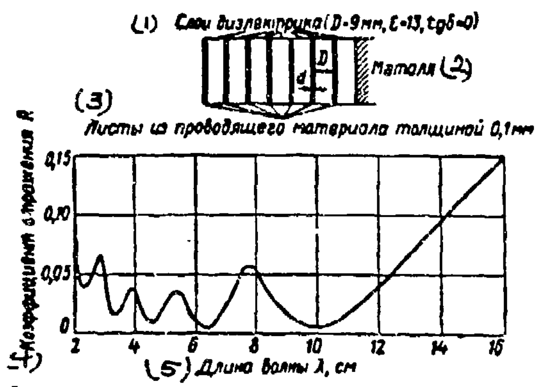

Fig. 2.

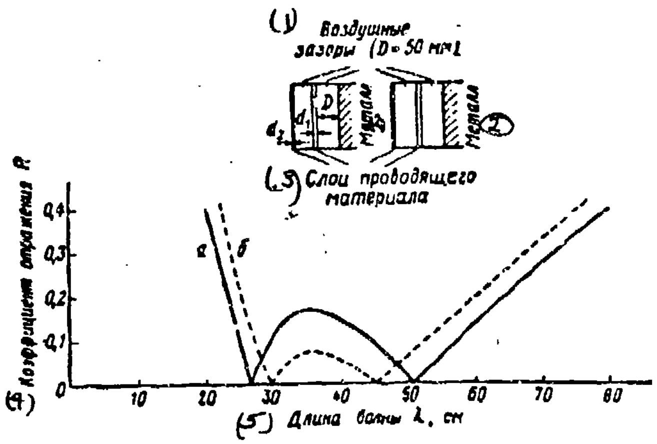

Fig. 3.

Fig. 2. Calculated dependence of coefficient of reflection of seven-layer radio-absorbing material from wavelength of absorbed radiation/emission. The skin drag of sheets composes 30; 14; 6, 5; 1, 1, 4; 0, 65; 0.3 kΩ/kV·inch (towards shielded metal).

Keys: (1). Layer of dielectric (D=9 mm, ϵ=13, tg6~0). (2). Metal. (3). Sheets from conducting material with thickness 0.1 mm. (4). Reflection coefficient. (5). Wavelength λ, cm.

Fig. 3. Calculated dependence of coefficient of reflection of two-layered radio-absorbing material from wavelength of absorbed radiation/emission. Layers of the conducting material (d_1=13 mm; d_2=0.6 mm; ϵ=50) with skin drag 125 and 0.27 kΩ/k,·inch (material

"a"); 2 and 0.23 kΩ/kV·inch (material "b").

Keys: (1). Air gaps (D=50 mm). (2). Metal. (3). Layers of conducting material. (4). Reflection coefficient. (5). Wavelength λ, cm.

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Value of required work depends on maximum permissible operating temperature of material. For the usual radio-absorbing plastics the maximum density of absorbed energy(without air cooling) is 0.155-0.465 W/cm^2 [5]. In the case special of the radio-absorbing materials this value can be led to 1.55 W/cm^2, and for the especially heat resistant radio-absorbing materials on the base of foam ceramics - to 7.75 W/cm^2. Value of absorbed energy depends on the heat transfer of material and can be increased with the safeguard of air circulation on the reverse side of material. The radio-absorbing material, from reverse side of which is secured the air circulation, can work in the range of temperatures from -60 to +650° C.

Majority of radio-absorbing materials is flameproof and fire retarding.

Radio-absorbing materials can be supplied in the form of elastic and rigid spongy materials, thin sheets, loose pouring mass and sealing compounds. Materials can be established/installed on the spot of use/application with the aid of the cement, or with the aid of the fastening devices. stability to the effect of atmospheric conditions, fuels/propellants and other factors is reached by applying the protective materials. Thus, for instance, the stability of radio-absorbing material on the base of neoprene to the effect of fuels/propellants and atmospheric conditions it is secured with coating from the nylon of the textiles of the edge of this material they are installed by special tape [5]. The typical dependence of the amount of the power reflected from the frequency of incident radiation for the materials of different types is shown in Fig. 5.

RADIO-ABSORBING MATERIALS FOR THE PROTECTION OF FLIGHT VEHICLES FROM RADAR RECONNAISSANCE.

Firm Conductron (USA), which specializes in region of study of radar sections, prepares number of ceramic (ferrite) radio-absorbing materials [1]. These materials do not worsen/impair their characteristics under the influence of rigid environmental conditions. Coatings from such materials are characterized by light weight, they will be brought in by thin layer, they possess stability to the effect of acoustic impact, chemical reagents, and also to the erosion under the effect of the high-speed circumfluent flow. Furthermore, these coatings are characterized by a good adhesion, it is comparatively easy possible to apply them in the curvilinear sections of the nose sections of the rockets.

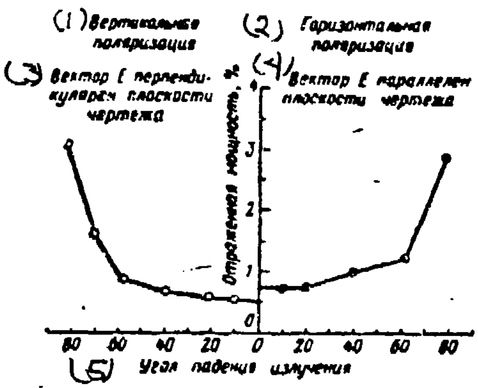

Fig 4.

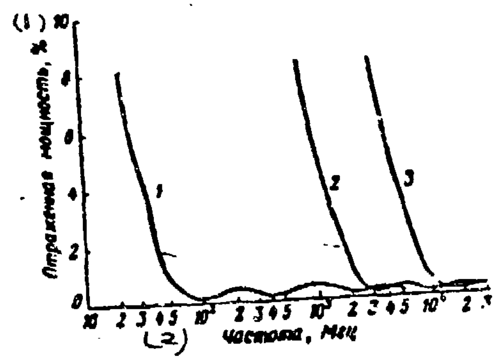

Fig. 5.

Fig. 4. Typical dependence of amount of radiated power, reflected by wide-range radio-absorbing material, from angle of incidence of radiation.

Keys: (1). Vertical polarization. (2). Horizontal polarization. (3). Vector E is perpendicular to plane of drawing. (4). Vector E is parallel to plane of drawing. (5). Angle of incidence/drop of radiation.

Fig. 5. Dependence of amount of power, reflected by different types of radio-absorbing materials, from frequency of incident radiation: 1 - pyramid from rigid spongy material with height/altitude of 1.8 m; 2 - sheet from rigid spongy material with thickness of 51 mm; 3 - sheet

from flexible spongy material with thickness of 9.5 mm.

Keys: (1). Reflected power. (2). Frequency, MHz.

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Such materials provide the absorption of electromagnetic radiation in the range of meter ones - decimeter waves, in this case weakening the reflection of energy is equal to 13 dB.

Other wide-range materials of firm Conductron provide absorption of radio emission in the range of meter ones - microwaves. Coatings from the materials of this type have a thickness of 6.3-12.7 mm and weaken/attenuate reflected radio emission 20-1000 times. One of such coatings with a thickness of 5 mm (1 m^2 this coating it weighs 4.9 kg.) provides weakening the radiation/emission reflected in the range from 40 to 3000 MHz to 1% in the middle part the range and to 7% on the edges of range.

Range of effective work of such coatings it can be expanded via combination of different ferrite materials. Developed by this firm materials were tested according to program REX. While conducting of tests for reflecting surfaces of the conical nose section of the rocket with the great lengthening there was applied the radio-absorbing coating of firm Conductron as one of the means of the decrease of radar section. The results of tests showed that this nose section actually/really has reduced radar cross section.

Firm Emerson and Cuming (USA) developed [8] material Eccosorb AN-W, intended specially of use/application on aircraft (Table 1). material is covered with nylon cloth from the neoprene, which possesses a good adhesion almost to all surfaces. It does not maintain burning and satisfies the requirements of military technical specifications MIL-C-20696. Its range of operating temperatures - from -60 to +150° C; material is characterized by weather and fuel-stability.

Another material of this form - Eccosorb-AN-W-ML is characterized by high insertion loss (40 dB), it is modification of material Eccosorb AN-W.

For use/application in aerospace flight vehicles firm Emerson and Cuming developed [9] wide-range radio-absorbing material of brand Eccosorb RM. It is the elastic organosilicon foam, capable of prolongedly working at temperatures to +260° C. The coefficient of reflection of material is less than 2% (weakening energy -17 dB). Change of the plane of the polarization of incident radiation or its angle of incidence little affect energy absorption. Eccosorb RM is released in the form of sheets by the size/dimension 300×300 of mm. With the thickness of 9.5 mm the weight 1 m^2 of material is 1.98 kg. It is intended for the work in the range 7.5 GHz and it is above. The material of such type with thickness of 28.6 mm, whose 1 m weighs 6.85 kg., must be used at the frequency of 2.4 GHz and it is above. The boundaries of the range of the use/application of material Eccosorb RM are not sharp.

Table 1.

The properties of the sheet materials Eccosorb AN-W.

(1) Марка	(2) Диапазон волн, см	(3) Отраженная мощность, %	(4) Размеры, см	(5) Толщина, мм	(6) Вес 1 м², кг
AN-W72	1,5 и короче (7)	1,5	60×60	3,2	0,5
AN-W73	4,0 » »	1	60×60	9,5	1
AN-W74	8,6 » »	1	60×60	15,9	1,5
AN-W75	12,5 » »	1	60×60	25,4	2,5
AN-W77	32 » »	1	60×60	63,5	4,5
AN-W79	66 » »	1	60×60	114,3	10

Keys: (1). Brand. (2). Wave band, cm. (3). Power reflected. (4). Sizes/dimensions, cm. (5). Thickness, mm. (6). Weight of 1 m², kg. (7). and it is shorter.

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In many instances this material can be used in the centimeter wave band. Eccosorb RM does not change its coefficient of absorption under the conditions of high humidity. Since the pores of material are open, is admissible utilization of ventilation (during the absorption of maximally possible values of energy). The pressure of the vapors of material is such, that it is ideally suitable for the wide fields of application on the objects of air-space technology. Sheets from material Eccosorb RM easily cut by knife or shears.

In the literature there are reports about possibility of developing materials, which convert electromagnetic energy into chemical. In the communication/report by the name "antiradar paint" (Anti-Radar Paint) [10] it is indicated, that as coatings of aircraft and rockets, which decrease the possibility from the detection by radars, can be used chemical substances, similar to the substances, used in the photographic emulsions. In the communication/report it is asserted that these substances will transform energy of radar radiation/emission into the chemical. The paints/colors, which exist at present, it is noted in the communication/report, are heavy, inclined to the peeling and the spallation and possess poor resistance to the effect of rain and unfavorable weather.

Significant attention abroad is paid to examination of plasma as radio-absorbing medium. The coworkers of investigation laboratories in the area of defense technology of firms General Motors, which work on project Defender, theoretically showed [11] that the effect of the absorption of radar radiation/emission and significant decrease of the effective surface of scattering can be obtained with the radar metal sphere, partially covered with layer plasma. The layer of plasma can be very thin in comparison with the wavelength of radar. This anomalous absorption can be the effect of diffraction, caused by the presence of the gradient of electron density in the plasma screen/shield, it speaks in the work.

Creation of combined heatproof-radio-absorbing materials is another direction in development of radio-absorbing materials for protection of aircraft and rockets. On the confirmation of firm Conductron [1] ablation heat shields can be obtained during the introduction of plastics to the composition of the radio-absorbing coatings, developed by this firm.

In the literature [6] are indicated also possibility of obtaining radio-absorbing system, which consists of oriented dipoles, arranged/located at a distance from the protected metal, equal to quarter wavelength. The properties of this system are determined by the sizes/dimensions of dipoles and by the parameters of their distribution. This system makes it possible to expand the frequency band, in which work narrow-band materials. For decreasing the overall thickness of this system the distance of the shielded metal, equal to $\lambda/4$, can be reduced to $(\lambda/4)\sqrt{\epsilon}$. Investigations [6] showed that for each length of the dipoles, utilized in the system, there is this lattice constant (bearing in mind the lattice, formed by dipoles), with which the coefficient of reflection has minimum value. It is indicated that the fundamental field of application of such absorbers is camouflaging objects from the detection radars, when are known the frequencies, at which transmitter [6] works. Characteristics of such absorbers are given in Fig. 6 and 7.

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RADIO-ABSORBING MATERIALS FOR THE ANECHOIC CHAMBERS.

Anechoic chambers give possibility of measurements under conditions, close to free space, independent of unfavorable climatic conditions. The problem of developing of chamber/camera, which would give the tolerance level of the echo signal in the place of reception/procedure in the range of frequencies from 50 MHz to 70 GHz [12] is at present set. Power level, reflected from the internal surface of chamber/camera, or the "cleanliness" ("quietness") of chamber/camera is its characteristic, expressed in the decibels.

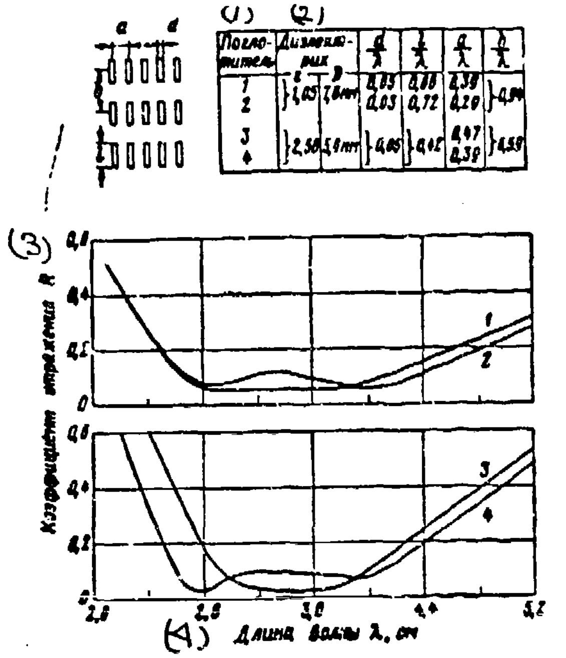

Fig. 6.

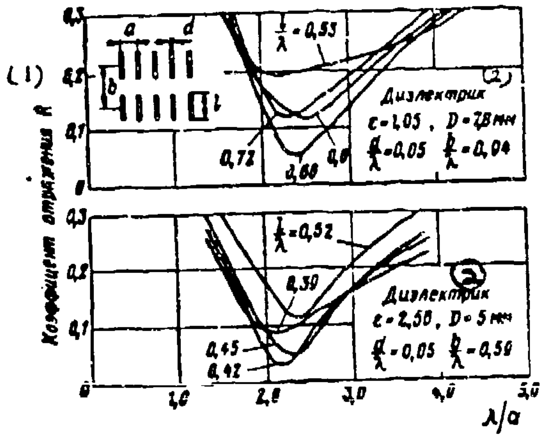

Fig. 7.

Fig. 6. Dependence of coefficient of reflection of different absorbers with dipoles from wavelength of incident radiation: 1 - dielectric constant; D - thickness of dielectric.

Keys: (1). Absorbers. (2). Dielectric. (3). Reflection coefficient. (4). Wavelength λ cm.

Fig. 7. Dependence of coefficient of reflection of absorbers with dipoles from lattice constant λ/a for different lengths of dipoles. Wavelength is λ=3.2 cm, the skin drag of dipoles 40 kΩ/kV·inch.

Keys: (1). Reflection coefficient. (2). Dielectric.

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The sense of this value is multivalent and in the specific cases depends on the character of work. For the case of the measurements of ant a characteristics this value is defined as the ratio of the density of the flow of the wave reflected to t ıe density of the flow of the incident wave in the assigned region of chambeı/camera, measured by the fixed/recorded types of transmitting and receiving antennas [13].

In USA won acceptance following types of anechoic chambers: chamber/camera with cross corrugations, chamber/camera with longitudinal corrugations and aperture type chamber/camera. In the chambers/cameras with the longitudinal corrugations the direction corrugation corresponds to direction from the emitter to the experienced/tested object. the maximum sizes of chambers/cameras 37×12×8 m. Walls floor and the ceiling of chambers/cameras with the longitudinal corrugations firm Emerson and Cuming covers/coats with the inexpensive radio-absorbing material Eccosorb FR-340.

Chamber wall, in which is located emitter, and wall, in which is located object being investigated, they have vertical tapered corrugation, covered with high quality radio-absorbing material Eccosorb CV-6 (Table 2).

Table 2. Radio-absorbing materials of firm Emerson and Cuming for the anechoic chambers.

(1) Марка материала	(2) Краткая характеристика	(3) Диапазон волн, *см*	(4) Отраженная мощность, %	(5) Размер блоков, *м*	(6) Толщина, *мм*
CV-6	(7) Пеноматериал, диэлектрик, не горит, 1 $м^2$ весит 4 *кг* (CV-6) и 6 *кг* (CV-9)	<4	0,01	0,6×0,6	152
CV-9		<12	0,01	0,6×0,6	228
CV-12	(8) Пеноматериал, диэлектрик, не горит, жесткий, 1 $м^2$ весит 8 *кг* (CV-12) и 12 *кг* (CV-18)	<32	0,01	0,6×0,6	305
CV-18		<66	0,01	0,6×0,6	457
FR-330	(9) Твердый пеноматериал, водонепроницаем, не горит, окрашен в белый цвет (материал FR-H) имеет те же параметры, но выдерживает температуры до 180°, 1 $м^2$ весит соответственно 2,4; 5; 10 *кг*	<13	1	0,9×0,3	50
FR-340		<32	1	0,9×0,3	100
FR-350		<66	1	0,9×0,3	200
FRL-330	(10) Материал для покрытия полов (модификация материала типа FR), 1 $м^2$ весит соответственно 3,5; 6 и 10 *кг*	<13	2	1×0,3	50
FRL-340		<32	2	1×0,3	100
FRL-350		<66	2	1×0,3	200
CHW-560	(11) Пеноматериал, твердый, с пленкой из стеклопластика, выдерживает нагрузку до 2 $кг/см^2$. Материал 580 и 590 — пеноблоки, 560 и 570 — пирамиды. Модификация CHW-H выдерживает температуру до 180°, 1 $м^2$ весит соответственно 9,5; 6,8; 3,6; 2,7 *кг*	<600	1	0,6×0,6	1830
CHW-570		<300	1	0,6×0,6	900
CHW-580		<150	1	0,6×0,6	450
CHW-590		<100	1	0,6×0,6	300
HT-98	(12) Керамический пеноматериал, не горит, интервал рабочих температур от —60 до +650° поглощает высокие уровни энергии, 1 $м^2$ весит соответственно 10, 14, 29 и 40 *кг*	<11	1		38
HT-99		<32	1	0,43×0,28	76
HT-101		<41	1		152
HT-102		<100	1	0,9×0,3	304

Keys: (1). Brand is material. (2). Short characteristic. (3). Wave band, cm. (4). Power reflected. (5). Size/dimension of blocks, m.

(6). Thickness, mm. (7). Spongy material, dielectric, do not burn, 1 m^2 weighs 4 kg. (CV-6) and 6 kg. (CV-9). (8). Foam material, dielectric, do not burn, rigid, 1 m^2 weighs 8 kg. (CV-12) and 12 kg. (CV-18). (9). Solid spongy material, is waterproofed, it does not burn, it is colored white (material FR-H) has the same parameters, but it maintains/withstands temperatures up to 180°, 1 m^2 weighs with respect to 2.4; 5; 10 kg. (10). Coating material of floors (modification of material of type FR), 1 m^2 weighs with respect to 3.5; 6 and 10 kg. (11). Spongy material, solid, with film from glass-fiber-reinforced plastic, maintains/withstands load to 2 kg/cm^2. Material 580 and 590 - foam-blocks, 560 and 570 - pyramid. Modification CHW-H maintains/withstands temperature up to 180°, 1 m^2 weighs with respect to 9.5; 6.8; 3.6; 2.7 kg. (12). Ceramic spongy material, does not burn, range of operating temperatures from -60 to +650° absorbs high energy levels, 1 m^2 weigh with respect 10, 14, 29 and 40 kg.

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Firm Boeing Aircraft Co uses attenuating material Eccosorb FR-330 for coating of internal surfaces of chamber/camera. Chamber wall is opposite to that, in which is placed the object being investigated, it is covered by high-quality attenuating material Eccosorb CV-6. Firm Republic uses for the chamber/camera with the longitudinal corrugations material Eccosorb CHW-580 for the especially precise measurements to the vertical corrugation of the prismatic form of chamber/camera above this material it is placed material Eccosorb CV-6. Firm ITT uses material Eccosorb FR-342 in combination with Eccosorb CV-9 (on the corrugations of opposite wall) for such chambers/cameras.

Aperture type chambers/cameras are used when for some or other reasons is one-way propagation of energy from transmitter to receiver. The fundamental designation/purpose of aperture construction/design lies in the fact that opening/aperture (aperture) prevented the direct illumination of lateral walls, floor and ceiling in the center section of the chamber/camera between the aperture and the anechoic zone. In order to reduce to a minimum undesirable diffraction on the aperture, they cover the open part from the side of transmitter by the high quality radio-absorbing material. The same material is used with the pasting of hollow inside the opposite chamber wall.

In anechoic chambers wide-range materials are used. For approaching the characteristics of materials to characteristics of free space the following methods are used: 1) to the front surface of attenuating material make up (cellular, spiny), which increases a number of reflections; 2) in the thickness of material gradually increase the content of the particles, which call electrical losses; 3) together use first two methods; 4) to the front surface of material adds flat/plane form, and an increase in the electrical losses is realized with the aid of special conical insert; 5) absorber is manufactured from several different layers of the material, which calls electrical losses, the magnitude of losses increasing/growing with an increase in the thickness of absorber [5].

Fundamental types of radio-absorbing materials for anechoic chambers are given below.

Material Eccosorb CH is prepared on base of animal hair (this absorber it possesses good electrical properties). The characteristics of material are given in Table 3.

Firm McMillan developed for anechoic chambers materials Type BB and BP for radiation absorption with critical frequency 50 MHz [14]. These materials are characterized by low stability, light specific weight/gravity and good electrical characteristics. The properties of these materials are given in Table 4.

From given tables it is evident that Eccosorb FR, which is used in the form of light foam-blocks, is most widely used brand of attenuating material for anechoic chambers. This absorbing material satisfactorily works in the very wide frequency range.

Table 3.

(1) Марка материала	(2) Диапазон волн, см	(3) Отраженная мощность, %	(4) Толщина, мм	(5) Вес 1 м², кг
CH-445	7 и короче(6)	1	25	1
CH-460	12 » »	1	50	2,5
CH-475	32 » »	1	100	4
CH-490	66 » »	1	200	7,5

Keys: (1). Brand of material. (2). Wave band, cm. (3). Power reflected. (4). Thickness, mm. (5). Weight of 1 m², kg.

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It has a coefficient of reflection -20 dB in the frequency band from 50 to 2.5 GHz with the thickness of the material (type FR-330) of 5 cm and to 450 MHz with the thickness of the material (type FR-350) of 20.3 cm.

With work at low frequencies serially produced material Eccosorb CHW especially is recommended. It is released in the form of the solid or hollow pyramids, assembled into the blocks, and also separate pyramids by the height/altitude to 1.8 m (type CHW-560) for the frequencies is below 50 MHz.

One of methods of affixing of materials of type Eccosorb FR consists of utilization of flexible and plastic H-shaped terminals/grippers, which protrude on 9.5 mm at 4 points of block, or blocks are fastened with the aid of special clamps; blocks can be stuck also on assembling surface by cement Eccobond 45.

Firm Plesse Co developed material of brand AF-20 [4] for anechoic chambers. This material is very the lung and solid. It consists of the pressed grains of foam polystyrene (space of grain 0.5 cm^3), surrounded by the strong/durable film of soot. The front of material is corrugated. The strength of material they increase by coating of coating on the front and rear surfaces of material. The coefficient of reflection of material in the range 4900-7050 MHz is equal to 0.01%, during a normal incidence in the radiation/emission and 0.75% at the angle of incidence of 70°.

Another material of brand AF-10 for anechoic chambers (firm Plessey) is prepared from natural porous natural rubber, mixed with coal dust. Material two-layered, absorption for each layer is different. During a normal incidence in the radiation/emission the coefficient of reflection of the 1st layer is equal to 6%. They decrease by the corrugation of its front surface to 1% in the range of the frequencies of 1550-5200 MHz and to 0.2% in the range of 5200-11 000 MHz. The third material of the same firm of brand AF-11 has smaller weight and consists of the finer/smaller grains: it is intended for range 4900-7050 MHz and higher frequencies.

Research laboratory of U. S. Navy (Naval Research Laboratory) in construction/design of anechoic chamber applied mats from animal hair, mixed with soot and neoprene [15]. This material is intended for the work in the range of waves from 1.2 to 14 cm. Technology of obtaining the solution of neoprene for the saturation of hair is such: is agitated on the rolls soot of brand Sterling 105 with the neoprene, after mixing to the mixture xylene before obtaining of solution by the viscosity/ductility/toughness of 25 centipoises [16] is added. The coefficient of reflection of such material is less than 2%, dielectric constant of upper layer 1.25-1.30 at the frequency of 500 MHz (Fig. 8).

Table 4.

(1) Марка материала	(2) Диапазон частот поглощаемого излучения, Мгц	(3) Уменьшение отражения, дб (4) угол падения излучения	
		15°	60°
BB-96	35 000—50	17	—
BP-96	35 000—75	—	17
BB-48	35 000—100	17	—
BP-48	35 000—150	—	17
BB-36	35 000—130	17	—
BP-36	35 000—195	—	17
BB-24	35 000—200	17	—
BP-24	35 000—295	—	17
BB-16	35 000—300	17	—
BP-16	35 000—400	—	17

Keys: (1). Brand of material. (2). Frequency band of absorbed radiation/emission, MHz. (3). Decrease of reflection, dB. (4). angle of incidence of radiation/emission.

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Firm B. F. Goodrich Sponge Products (USA) releases attenuating materials from urethane for anechoic chambers. Materials are prepared in the form of the blocks with a length of 1.8 m, the area of the foundation of block 0.2 m^2. Such blocks are greatest of the blocks, used in the anechoic chambers. Chambers/cameras with the skin/sheathing from this material are intended for the determination of the characteristics of the antennas of the artificial satellites, which will investigate space within the moon orbit according to program Explorer B. Range of the measurements of this chamber/camera 136 MHz [17].

SHIELDING RADIO-ABSORBING MATERIALS.

Shielding radio-absorbing materials are usually narrow-band and consist of layer, by thickness into quarter wavelength, superimposed on electric shield, that calls electrical losses. Thickness of the layer is equal to quarter wavelength. The value of the electrical losses of material is such, that the amplitude of wave, passing through this material, and waves, reflected from the screen/shield, are equal, in this case both waves are shifted relative to each other by $\lambda/2$, i.e., they are located in opposite phases and mutually are extinguished.

Shielding materials are developed/processed in essence by firms Du Pont de Nemours and Co., PlesseyCo, B. F. Goodrich Sponge Prod., McMillan Co., Emerson and Cuming Co.

Firm Du Pont de Nemours and Co. (USA) obtained patent [18] for narrow-band shielding radio-absorbing material, which consists of neoprene film with filler from powder carbon. Film is solidly connected with the metal foil. This material absorbs the electromagnetic radiation of the specific frequency in the range 10^{7}-10^{11} Hz. The chemical composition of neoprene film (in the parts by weight): 2-chlorine-1.3 butadiene (neoprene) - 36.1; graphite with a density of 2.25 g/cm^{3} - 20; Semi-Reinforcing Furnace Black with a density of 1.8 g/cm^{3} - 18.01; the carbonate of calcium - 18.05; phenyl-α-naphthylamine - 0.7; oxide of zinc - 1.8; calcined oxide of magnesium - 1.5; stearic acid - 0.2; high-melting solid paraffin - 1.8; petroleum oil - 1.8.

All these components mixed before obtaining of homogeneous mixture, subjected then to glazing at 48° C with obtaining of film with thickness of 0.96 mm. After vulcanization the film had a limit of strength 67.5 kg/cm^{2} with relative elongation 160%.

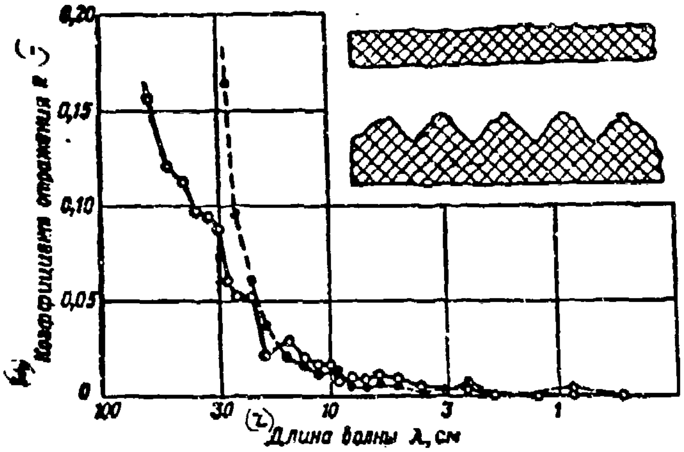

Fig. 8. The dependence of reflection coefficient from the wavelength of the absorbed radiation/emission for the flat/plane material and the material, whose front surface has pyramidal flanges.

Keys: (1). Reflection coefficient. (2). Length of wave λ, cm.

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Then film was cut into the squares 250×250 mm; four such squares were placed (one on top of the other) on the uncoated aluminum foil with a thickness of 0.05 mm. In this case three lower squares were arranged/located so that the direction of their calendering coincided, and the fourth (upper) square was located at the right angle to the lower ones. The obtained 4-layer film with the foil underwent extrusion/pressing on the hydraulic press at 140° C during 30 min. After cooling under the pressure to 30° C neoprene backed film had a thickness of 3.7 mm. The film of this chemical composition absorbs electromagnetic radiation with a frequency of $3 \cdot 10^9$ Hz.

For creation of neoprene cement, absorbing radio waves with frequency of $7.5 \cdot 10^9$ Hz, is developed [18] special technology. In cement are included 150 parts of neoprene; 3 parts of phenyl-β-naphthylamine; 7.5 parts of oxide of zinc; 6 parts of calcined oxide of magnesium; 0.75 parts of stearic acid; 84 parts of Semi-Reinforcing Furnace Black and 494 parts of xylene. For this phenyl-β-naphthylamine, oxide of magnesium, oxide of zinc and furnace black mixed in the mixer of Bandbury type during 3 min at 43° C, then they reduced temperature to 35° C and was added neoprene. After this, during 7 min they raised the temperature to 88° C. Mixing occurred 5 min at 88-93° C. The obtained composition was placed into the rolls, where into it zinc oxide at room temperature was added. This mixture, prepared on the cold rolls, they mixed in paddle agitator and was added half of the content of xylene, after which the mixing was continued 5.5 more hour. The obtained solution of cement, which contains 33.7% by the weight of solid, was filtered through the cloth filter for the removal/distance of the undissolved clots. Then the uniform composition, suitable for the plotting on the surface was prepared by usual spatula. For this 171 parts by weight of the neoprene cement (containing 33.7% solid) were mixed with 12.6 parts by weight of graphite and 42 parts toluene (in this case components were cleaned in the closed container during 16 hours). The obtained solution was brought in to the surface of glass plates/slabs (preliminarily covered with the polyvinyl film with thickness 0.025 mm) and was dried out during 30 min. at room temperature. By the same method they were brought in 9 additional layers coatings. Finished coating was removed/taken from the glass plate/slab, they maintained/withstood at 70° C during 24 hour for the solvent elimination and vulcanized at 140° C for 1 hour.

Vulcanized film with thickness of 0.5 mm contained 11.9% (by space) of graphite and 22.7% (by space) of furnace black. Three such films were placed by one on another and underwent extrusion/pressing. In the pressed form the film absorbs electromagnetic radiation with the frequency $7.5 \cdot 10^{9}$ Hz.

For absorption of radiation/emission of lower frequencies in the range 10^{7}-10^{11} Hz one should use more effective forms of carbon (graphite and acetylene black), in this case their content in film they increase (in space) to 25-50%.

During absorption of higher frequencies it is preferable to use furnace black, in this case their content in film they reduce to

8-25% (by space).

Tolerance for average/mean thickness of film should to compose ±0.5% of its thickness. The films, obtained according to this patent, are characterized by high corrosion resistance.

The same firm developed narrow-band attenuating material with filler from scaly alu. num [19]. Material is the pigmented film with the bonding agent from the film-forming polymer on the base of mono-olefin aliphatic hydrocarbon. The content of filler by the weight composes 25% in this case the scale of aluminum are partially oriented with respect to the plane of material.

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Technology of the manufacture of material is such: 45 parts by weight of scaly aluminum with the average/mean thickness of the scales of 0.3 μm; 33 parts by weight 15% xylene solution of polyisobutylene (with dielectric constant 2.3 with 1000 kHz) and 40 parts by weight of xylene mix before obtaining of uniform mixture. The obtained mixture undergoes degassing at a pressure 100 mm Hg for the removal/distance of blisters from the mixture. Then mixture will be brought in to the glass plate/slab and is dried during 2 days at room temperature. Then the film of mixture is removed/taken from the glass plate/slab and is kilned. The thickness of film 0.08-0.10 mm; it contains 90% of aluminum filler. Finished film has bright surface, which indicates good orientation of metallic scales in the plane of film. This film after connection with the metal foil absorbs the electromagnetic radiation of the specific frequency[1] in the range 10^{4}-10^{11} Hz.

FOOTNOTE [1]. In the literature the frequency is not given. (Notes of compiler) ENDFOOTNOTE.

For obtaining radio-absorbing material according to the same patent it is possible to use as binder butyl rubber. Material is prepared as follows: 50 parts by weight of butyl rubber with dielectric constant 2.3 with 1000 kHz, 2.5 the part by weight of zinc oxide, 0.5 the parts by weight of the disulfide of tetramethylthiocarbamide and 1.5 parts by weight of sulfur they are ground on the cold rolls during 18 min before obtaining of uniform mixture. 25 parts by weight of the obtained mixture are dissolved 100 parts of xylene. To 40 parts by weight of this solution add 32 parts by weight of the thin aluminum scales and 60 parts by weight of xylene. This mixture is agitated, undergoes degassing at a pressure 100 mm Hg to the removal/distance of bubbles from the mixture. After degassing the mixture will be brought in to the glass plate/slab, hour is dried during 24. The obtained film then is removed/taken from the glass. After secondary drying during 16 hour during 70° C and vulcanization at 145-150° C during 20 min the obtained flexible film with a thickness of 0.08 mm, which contains 80% of scales of aluminum, has a limit of strength 29 kgf/mm^2 with relative elongation 25%. It absorbs the electromagnetic radiation of the specific frequency[1] in the range 10^6-10^{11} Hz.

FOOTNOTE [1]. In the literature the frequency is not given. (Notes of compiler) ENDFOOTNOTE.

Fundamental difficulty during manufacture of resonance type radio-absorbing materials consists in monitoring of thickness of the layer of material. For its overcoming in the USA the method of the monitoring of the thickness of the layer of the radio-absorbing material, which is characterized by high accuracy [20], is developed. According to this method the thin gauge sheet of material (consisting of the connecting/cementing with the scaly filler substance) with the thickness somewhat of smaller than the nominal thickness of material (quarter wavelength) it will be brought in and is dried out on the flat/plane, flat surface. Then film is removed/taken and its thickness (it is used, for example, micrometer) is measured by standard method. After this, to the reverse side of film it will be brought in layer of cement - the dielectric of the accurately adjustable thickness. The thickness of glue film is selected so that together with the thickness of the radio-absorbing material it composes quarter wavelength. Then the radio-absorbing coating will be brought in to the object.

Investigation center Allen Clark Research Center firm Plessey developed materials, which make it possible to remove undesirable reflections of signals of RLS, which occur with work of radar systems of landing. On the confirmation of firm the construction/design of these materials answers complex mathematical formula. The base of materials are rubber, plastic or ceramics, and fillers - magnetic and dielectric substances. Firm developed two type of the materials: the wide-range material, which absorbs different wavelengths (maximum length of the absorbed wave it is determined by the thickness of material), and the thinner resonance attenuating material, utilized for one or two ranges.

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These materials absorb 99.99% of incident radiation and are produced on the industrial scale at the plant of firm Plessey in the city of Towcester. The need for such materials is caused by the fact that the reflections of radar signals of RLS, which gives accurate coordinates for the recovery into airport zone, from the system of approach lights and instruments of the illumination of takeoff and landing strip become indistinguishable (in the final, critical landing phase) from the signals, reflected from the aircraft. Screens/shielmaterials of firms Plessey, established/installed on the instruments of illumination and approach lights, excluded this type of interferences. These materials were successfully used in the airport of Zurich (Switzerland) [21, 22, 23]. In the literature it is indicated [24] that as the filler the firm recommends the using of aluminum flakes, soot, ferrites, carbon, and also alloy by nickel steel in the powder-like form. It is noted [25] that these materials can be used also under the marine conditions for antijamming with the work of navigational radar equipment.

Firm Bendix (USA) applied shielding radio-absorbing materials in system Microvision developed/processed by it for blind landing. This system makes it possible to produce landing on the image on the screen of the cathode-ray tube of the signals of radio beacons, placed on both sides of takeoff and landing strip. System Microvision works on the wave 3 cm. The radio-absorbing materials from the hair, saturated by natural rubber are applied for manufacturing the absorbers of the antenna system of the ground-based radio beacon of the systems (absorbers they are used for the suppression of minor lobes). Radio-absorbing separators [26, 27, 28] from this material are used into the onboard antenna to system (entering system Microvision). These separators surround the horn antennae, placed in pairs in both planes symmetrically relative to the longitudinal axis of aircraft. Separator from the rubberized hair absorbs the reflections of radar signals from the parts of aircraft.

Firm B. F. Goodrich Sponge Production developed shielding attenuating material of type RS from plastic. This material also makes it possible to decrease undesirable distortions by the screens/shields of RLS, which appear with the reflections from the close objects/subjects - masts, antenna observation towers and other metal constructions. A material of the type RS is the thin elastic plastic sheet, which to admissibly treat by the methods of machining and to bend. It is possible to cover/coat the metallic parts of any form with this material. Material is characterized by high wear resistance and can work as with the high ones (to 205° C), that and with negative temperatures, and also in the conditions of solar radiation, wind loads and rain. Material of type RS is intended for work in the 3-cm range. One square meter of the sheet of the material with a thickness of 1.78 mm weighs 4.9 kg. The material with a thickness of 1.78 mm weakens/attenuates reflection by 35 dB at the wavelength 3.2 cm, by waves 3.1 and 3.3 cm respectively 28.5 and 26 dB, by waves 3.0 and 3.4 cm respectively 27.5 and 21 dB [29] (Fig. 9).

For use/application on military and passenger aircraft firm

McMillan created shielding material of type T, intended for absorbing radar radiation/emission of specific frequency in the range 2500-35000 MHz. A material of the type T extensively is used in aircraft DC-3, DC-6, DC-7, Constellation, Viscount, Convair; it is intended for the protection of airborne RLS from the interferences, caused by the undesirable reflection of signals. Furthermore, a material of the type T shields aircrew from the harmful radiation effect of airborne RLS. A material of the type T is characterized by light weight, elasticity, prolonged service life and high effectiveness. Its characteristics are such: dissipated power 0.465 W/cm^2, the range of operating temperatures from -50 to + 130°.

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With the thickness of 2.4 mm 1 m^2 of material weighs 0.76 kg. (for the radiation absorption by a frequency of 35 000 MHz), while with the thickness of 1.6 mm - 0.83 kg. (for radiation absorption by a frequency of 24 000 MHz). For thickness 4; 7; 14 mm the corresponding values of weight and frequencies are equal to 1.4 kg. (for 9375 MHz), 1.7 kg. (for 5400 MHz), 3 kg. (for 2800 MHz). The standard size/dimension of the sheets of a material of the type T is equal to 450x900 mm. On the edges this material is installed.

(after installation to the aircraft) by cement Bostik 4585. The reflection factor of energy of a material of the type T composes 0.3 to 2% depending on the angle of incidence of radiation/emission [30].

Firm Emerson and Cuming developed series of resonance shielding materials for antenna fairings about aviation RLS, masts, etc. These materials of brand Absorber type SF are released in England by the branch of separation/department Electronics Division firm Microcell Ltd. Materials are intended for absorbing the resonance frequencies, beginning from 1 GHz and (through the intervals on 0.5 GHz) to 24 GHz. The base of materials is organosilicon natural rubber with the thermal stability from -50 to + 125° C. Materials are water/aqueous-not penetrated, they do not worsen/impair their properties under the influence of the unfavorable weather conditions and other factors (for example, the radio emission of high power). These materials reflect less than 1% incident radiation (weakening 20 dB). The thickness of this material for the work at the frequency of 5.5 GHz is equal to 2.3 mm. Materials Absorber type SF, utilized in the ranges 3 cm and K (0.83-2.75 cm) possess an even smaller thickness. In connection with this the materials indicated easily are bent and take well the form of the complex layout of object with the low bending radii. For connecting these materials with others the cement of brand Bond SF-C, applied to the substratum from the ground of brand Primer 33 [31], is used.

MATERIALS FOR THE CREATION OF DISSIPATIVE ELEMENTS IN THE WAVEGUIDES AND THE COAXIAL LINES.

In high-frequency devices radio-absorbing materials are used as terminations, attenuators, dummy antennas and other elements/cells.

Typical technology of manufacture of such material is described in patent of firm Semicon of California for material, which absorbs electromagnetic waves of high frequency. Material consists of the particles of the metal, which possess high resistor/resistance and dispersed of the dielectric binder. Strength of materials can be changed in the dependence on the parameters of technological process. Material it is possible to metal-clad, furthermore, it is soldered well. Technology of obtaining this material is such: oxides of aluminum (they can be used and other refractory metals, for example, molybdenum) first mix by 50% of tungsten powder with 50% of powder. Size of the particles of the powder 4 μm. They will mix the mixture of powder into the mold, where is realized forming part at pressure 1400 kg/cm^2. For the forming it is possible to use and other methods of extrusion/pressing (hydrostatic extrusion/pressing), and also slip casting.

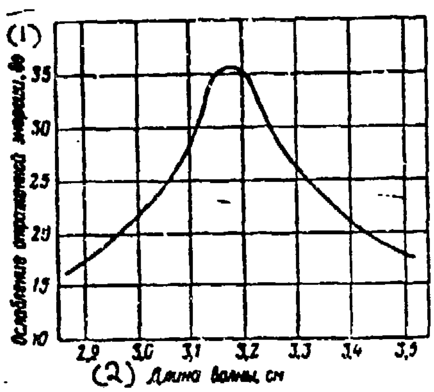

Fig. 9. Dependence of the value of weakening the reflected energy from the wavelength for the material of the type RS.

Keys: (1). Weakening of reflected energy, dB. (2). Wavelength, cm.

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The obtained billet undergoes mechanical processing on turning or other machine tool before obtaining of required dimensions and form. Then part is annealed/scorched in the furnace in the inert atmosphere at 1700° C during 10-20 min. The resistor/resistance of part can have a value of 1 Ω/cm - 500 MΩ/cm depending on pressure and temperatures of extrusion/pressing, size of particles and content of metal. The required value of resistor/resistance it is possible to obtain also via the additive of small quantities of titanium. This material effectively works in the range of the frequencies of 400-30 000 MHz

[32].

Firm Custom Materials (USA) developed radio-absorbing organosilicon material of brand Custom Load of 4201 for manufacturing dissipative elements of waveguides. Material is capable to absorb large power on centimeter waves. It is released to the limits of attenuation from 8 to 80 dB/cm (with 10 GHz). Range of operating temperatures of material from -50 to +265° C, water absorption are less than 1%. Material is capable to absorb energy levels, to 50% exceeding permissible energy levels for the materials, created on the base of epoxies. Material is released in the form of bars and sheets, it can be subjected to machining for obtaining the parts of complex form [33, 34].

Number of materials for manufacturing dissipative elements of high-frequency equipment is developed by firm Emerson and Cuming. Materials Eccosorb MF110-124 are characterized by a good attenuation and high strength, they work to the temperature 180° C. Material Eccosorb 500F has the same characteristics, as materials MF110-MF124, but it is capable of working at temperatures to 260° C. Material Eccosorb CR has the same properties, as material Eccosorb MF117, but it is supplied in the form of the sealing compound. Materials Eccosorb HF are characterized by high impact toughness and are used to the temperature 150° C. Material Eccosorb WG is ceramic foam with a density of 1.28 g/cm^3, it is intended for absorbing of frequencies below 1000 MHz and works to the temperature 540° C. Materials Eccosorb PM are supplied in the form of loose pouring composition and harden on the spot of use/application, forming rigid foam with the high attenuation. Materials Eccosorb BR with a density of 0.32 g/cm^3 also are the ceramic foam, which calls high losses and which works at temperatures to 430° C. Material Eccosorb LS is the elastic foam, which is characterized by a good adhesion to different materials and used at temperatures 150° C [8].

Properties of enumerated materials are given in Tables 5-9.

CHARACTERISTIC MEASUREMENTS OF RADIO-ABSORBING MATERIALS.

Such measurements are realized with the aid of comparatively simple instruments. The coefficient of reflection of material is determined in a following manner: the level of the signal, reflected by material with the metallic support/base, it is compared with the level of the signal, reflected from one metallic support/base (without radio-absorbing material). Usually in this case use two horn antennae, arranged/located on the supports (supports it is possible to move in the vertical plane on the arc of semicircumference). By means of regulation of the angle of radiation of the horn antenna of transmitter with respect to the horn antenna of receiver is measured the coefficient of reflection of material at different angles for the horizontally and vertically polarized radiation. Reflection coefficient is determined [4] according to formula $R=P_1/P_2$, where P_1-level of the power of the oscillations, reflected by material, P_2-level of the power of the oscillations, reflected by metal sheet, R - reflection coefficient. It is most complicated to conduct these measurements at the zero angles of radiation/emission, since radiant energy is here transmitted directly between two antennas.

Page 132. Table 5. Properties of materials Eccosorb MF with $3\cdot10^{9}$ Hz.

(1) Марка материала	(2) Диэлектрическая постоянная	(3) Тангенс угла потерь	(4) Магнитная проницаемость	(5) Коэффициент рассеяния	(6) Затухание, дб/см
MF124	26	0,114	4,0	0,48	17
MF117	21,8	0,068	3,4	0,25	7
MF116	15,7	0,060	3,0	0,12	5,8
MF114	10	0,055	1,9	0,10	1,9
MF112	5,2	0,048	1,3	0,07	0,7
MF110	3,5	0,040	1,1	0,01	0,3

(7) Свойства материалов Eccosorb MF при 10^{10} *гц*

MF124	25,8	0,118	2,1	1,2	69
MF117	21,2	0,074	1,6	0,75	34
MF116	16,6	0,062	1,2	0,50	24
MF114	9,7	0,058	1,0	0,36	12
MF112	5,1	0,051	0,9	0,25	5
MF110	3,3	0,047	0,9	0,18	2,5

Keys: (1). Brand of material. (2). Dielectric constant. (3). Loss tangent. (4). Magnetic permeability. (5). Coefficient of scattering. (6). Attenuation dB/cm. (7). Properties of materials Eccosorb MF with 10^{10} Hz.

Table 6. Properties of materials Eccosorb HF.

(1) Марка материала	(2) Показатели	(3) Частоты, при которых измерялись свойства, гц			Сопротивление, ом/см (4)
		10^4	10^7	$8{,}6 \cdot 10^9$	
HF155	(5) Диэлектрическая постоянная Тангенс угла потерь	23000 330	1000 7	50 0,8	$10—10^2$
HF680	„ „	—	—	35 0,4	$10^2—10^3$
HF853	„ „	— —	— —	20 0,30	$10^3—10^4$
HF1000	„ „	— —	—	15,0 0,2	$10^4—10^5$
HF2050	„ „	—	—	8,0 0,08	—

Keys: (1). Brand of material. (2). Indices. (3). Frequencies, with which were measured properties, Hz. (4). Resistor/resistance, Ω/cm. (5). Dielectric constant. Loss tangent.

Table 7. Properties of materials Eccosorb PM in the decimeter, centimeter and millimeter wave bands.

(1) Марка материала	(2) Диэлектрическая постоянная	(3) Тангенс угла диэлектрических потерь	(4) Затухание, дб/см	(5) Сопротивление, ом/см	(6) Плотность, г/см³
PM-A	1,5	0,15	1,5	—	0,4
PM-B	4	0,8	10	2000	0,4
PM-C	50	0,5	20	20	0,48

Keys: (1). Brand of material. (2). Dielectric constant. (3). Dielectric power factor. (4). Attenuation, dB/cm. (5). Resistance, Ω/cm. (6). Density, g/cm³.

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The measurement of KSVN [VSWR] is realized on the installation, encompassing the horn, which is matched with the free space. The sizes/dimensions of horn are selected so that the aperture angle would be less than 12°. The dependence, which joins the coefficient of reflection and KSVN, takes the form

$$R^2=\frac{1-\frac{V_{\text{мин}}}{V_{\text{макс}}}}{1+\frac{V_{\text{мин}}}{V_{\text{макс}}}},$$

where R - reflection coefficient, $V_{\text{мин}}$ - minimum value of KSVN and $V_{\text{макс}}$ - maximum value of KSVN. The short-cut method of the rapid determination of dielectric constant and dielectric power factor of the radio-absorbing materials is developed by firm Electronic Warfare Laboratories of USAF of the USA [35]. The method of measurement of the dielectric constant of the materials, providing attenuation of approximately 17 dB, is described in work [36].

Firm Parametric on contract with USAF [United States Air Force] developed method of evaluation/estimate of radio-absorbing materials for flight vehicles according to their characteristics at audio frequencies [37]. Method is based on the measurements of the capacity in the range of audio frequencies, whose value is connected with the orientation and the parameters of the distribution of conductors in nonconducting material. The development of this method is caused by the fact that for the evaluation of the reflection of radar signals from the flight vehicles, covered with the radio-absorbing material, this characteristic, as the dependence of reflection coefficient from the viewing angle and frequency, is necessary, but insufficient. The operations/processes of control of technological process require the information, which indicates the local deviations from specification, since even the localized defects of the radio-absorbing materials condition the unfitness of materials for the protection of flight vehicles.

As a result of investigations it is established that dielectric measurements at audio frequencies give part of required information, since results of these measurements are connected with composition and structure of materials and with their behavior under the effect of effect of radar signals. Thus, it is possible to predict the high-frequency characteristic of materials, on the basis of the measurements at the audio frequencies.

Table 8. Properties of materials Eccosorb BR. Values are given for the frequencies of 800-10000 MHz. Insertion lcss for the sheet with a thickness of 6.3 mm in the centimeter wave band.

(1) Марка материала	(2) Диэлектрическая постоянная	(3) Тангенс угла потерь	(4) Вносимое затухание, дб
BR240	10	0,8	40
BR250	6	0,4	20
BR260	3	0,2	10

Keys. (1). Brand of material. (2). Dielectric constant. (3). Loss tangent. (4). Insertion loss, dB.

Table 9. Properties of materials Eccosorb LS.

(1) Марка материала	(2) Диэлектрическая постоянная	(3) Тангенс угла потерь	(4) Вносимое затухание, дб	(5) Коэффициент ослабления при отражении энергии, дб
LS-22	1,8	0,5	5	15
LS-24	4	0,8	10	10
LS-26	10	1,2	15	5

Keys: (1). Brand of material. (2). Dielectric constant. (3). Loss tangent. (4). Insertion loss, dB. (5). Coefficient of weakening with reflection of energy, dB.

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From the point of view of production control and other consideration the utilization of measurements at the audio frequencies as the additional method presents special advantages in comparison with some shf measurements alone.

Experiments on sonic ones and radio frequencies were conducted initially with "idealized" material from acrylic panels, with which were connected filaments from molybdenum wire with diameter of 0.0254 mm. The distances between the filaments corresponded to the following intervals in 3-cm range: $\lambda/2$, $3\lambda/8$, $\lambda/4$ and $\lambda/8$. The measurements of insertion losses in this range showed that the wire filaments, perpendicular to electric field, with it do not interact, while for the filaments, parallel with field, insertion losses rapidly increased/grew, when the distance between them became less than quarter-wave length. Measurements at the audio frequencies consisted in determination of the capacity of comb probe with two input terminals at the frequency of 10 kHz. It was established that also at the audio frequencies and in 3-cm range (at the frequency of 10 GHz) the capacity of probe depends on the distance between the wire filaments and their orientation.

Taking into account simple correlations between results of measurements at frequencies of 10 kHz and 10 GHz for idealized material experiments were carried out on aviation radio-absorbing materials (base epoxies) and on material from polyurethane foam of low density. These experiments also showed that despite the fact that the dielectric measurements, especially at the low frequencies, to a certain degree were sensitive to such factors as structure of matrix/die, density, drying regime and humidity, for a large number of aviation radio-absorbing materials on the base of epoxy compounds the determination of distributions and orientation of filaments at the audio frequencies will agree with characteristics of material at the superhigh frequencies. It is assumed that the systematic evaluation/estimate ot materials can indicate the degree of the correlation between the results of the measurements of dielectric characteristics at the low frequencies and the characteristics of materials at the superhigh frequencies.

In work [37] it is indicated that promising radio-absorbing materials will be characterized preferably by such variables, which can be measured on flight vehicle or other large-size unit. By these variables there can be capacity and losses at sonic frequencies, they are measured by small testing probe, but not complete dielectric constant at frequencies L, S, C or the X ranges (19.3-76.9 cm, 5.77-19.3 cm, 4.84-7.15 cm, 2.75-5.77 cm), which, in spite of it it is substantial value, it is difficult to determine directly at the assigned point on the real object.

CONCLUSIONS.

In the last 3-5 years in the USA activity of scientific research organizations and firms for development of radio-absorbing materials was enforced. Are developed and are produced on the industrial scale both the narrow-band and wide-range materials, which ensure absorption by 99.99% of feeding radiation/emission.

Problem of further investigations in USA is development of most technologically effective form of radio-absorbing material of coating, combining good manufacturability during application on object, light weight and sufficiently low reflection coefficient. The fundamental difficulty of designing of this coating consists in the fact that with low to thickness it must possess good physical ones, by electrical and magnetic properties.

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Creation of combined heatproof-radio-absorbing coatings for nose sections of rockets, which possess good ablation and radio-absorbing properties, is new direction in development of radio-absorbing materials in USA.

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